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DETERMINATION OF NONPROPAGATION DISTANCES FOR 105-mm HEAT-T CARTRIDGES M456

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This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in production of Army materiel.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Nonpropagation distance	Composition B
105-mm HEAT-T projectile M456	M30 propellant
M83 primer	MMT-ammunition
M148 cartridge case	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of tests were conducted to establish the nonpropagation distances between various subcomponents and assemblies of the 105-mm HEAT-T cartridges M456. Five simulated loading line configurations were initially considered for testing: M83 primers, M148 cartridge cases, M456 projectiles, and M456 cartridges vertically and horizontally oriented. This effort was in direct support of the modernization of the Milan Army Ammunition Plant, Milan, Tennessee, but it is applicable to other similar facilities. The test results were as follows:
(cont)

1. M83 primers will not rupture their containing M148 cartridge case, therefore nonpropagation tests were unnecessary.

2. Use of the complete cartridge nonpropagation distance for both the loaded M148 cartridge case and the M456 projectile conveyor spacing is a valid "worst" case substitution.

3. The safe nonpropagation distance for fully loaded M456 cartridges is 58.4 centimeters (23.0 inches) in a vertical orientation and 38.1 centimeters (15.0 inches) in a horizontal orientation, provided 7.6 centimeter (3.0 inch) diameter aluminum bars (6061-T6) are used as shields between cartridges in both cases. (These are not minimum distances, but are tailored to fit a given loading line situation.)

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INTRODUCTION

Background

At the present time, an Army-wide modernization and expansion program is currently underway for the purpose of upgrading existing and developing new Load-Assembly-Pack (LAP) manufacturing explosive facilities. This effort will enable such facilities to achieve increased production cost effectiveness with improved safety, as well as provide manufacturing facilities for new improved weaponry within existing LAP manufacturing facilities.

As part of the overall modernization and expansion program, the Special Technology Branch, Energetic Systems Process Division, LCWSL of ARRADCOM, Dover, New Jersey, is engaged in the development of system safety criteria in support of ammunition plant LAP operations.

The essential component of this program, titled "Safety Engineering in Support of Ammunition Plants", is the development of safe separation (non-propagation) distance criteria for munition end-items and bulk explosive materials. Such criteria, when developed under this program, will be utilized as the basis for the design of all explosive production installations and the modernization of existing ones.

The activities described in this report should provide safety criteria to support facility modernization efforts in the RISI Industries overall line concept at Milan AAP, Tennessee, where a family of 105mm tank cartridges (M456, M490, M735 and XM775) are being assembled. Since the 105mm M456 HEAT-T Cartridge contains the greatest amount of explosive materials, it was used in determining the safe separation distance for the 105mm cartridge family.

Objective

The primary objective of this program was to determine experimentally, the safe separation distance between various configurations of fully loaded 105mm M456 HEAT-T cartridges and their components, as they are transported on conveying systems. The data obtained from this program will help determine the safe separation distance between units on the conveying system, conveyor speeds, and the rate of production of this family of 105mm tank cartridges.

The overall program objective is to supplement and/or modify existing safety regulations, and criteria pertaining to the safe spacing of ammunition and other energetic materials in order to assist explosive loading plants in their LAP facility layouts for the most effective and economic man-machine relationship.

Criteria

This test program was implemented to determine the safe spacing of 105mm M456 HEAT-T Cartridges and their components under simulated loading plant conditions and/or the necessary shielding between projectiles, such that the effects of a major accidental detonation of a munition on the assembly line will be limited to the immediate area or loading bay, and not propagated to adjacent loading activities. Therefore, the only acceptable criteria to establish the safe separation distances is the non-propagation of the donor detonation to the acceptor units.

Note that all separation distances cited in this report were measured between axial centerlines of the donor and acceptor units.

TEST CONFIGURATION

General

Testing of the 105mm M456 HEAT-T Cartridges to determine the minimum non-propagation distance between donor and acceptor units was begun in August 1980 and completed in October 1980. All testing was conducted at the National Space Technology Laboratories in Mississippi, under the auspices of the ARRADCOM Resident Operations Office. This was in conjunction with the Hazard Range Support Unit of the Computer Science Corporation.

The test program consisted of five portions, each portion corresponding to component and cartridge assembly locations on the overall assembly line of the 105mm M456 HEAT-T Cartridge (fig. 1). These locations are as follows:

1. Between Stations 9 and 13 on the automatic primer insertion machine: cartridge cases vertically oriented and inverted (open end down) with M83 Primers inserted.

2. Between Stations 15/16 and 19/20 on the dual main assembly conveyor: cartridge cases vertically oriented (open end up), fully loaded with approximately 5.6 kg (12.5 lb) of M30A1 Propellant, and with the M83 Primer inserted.

3. Between Stations 25/26 and 19/20 on the parallel supply conveyor: projectiles containing 0.97 kg (2.14 lb) of explosive Composition B, oriented vertically.

4. Between Stations 19/20 and Station 33 on the dual main assembly conveyor: fully loaded cartridges (projectile plus loaded cartridge case) oriented vertically (fuze end up).

5. Between Stations 33 and 38 on a pack-out walking beam conveyor: fully loaded cartridges (projectile plus loaded cartridge case) oriented horizontally (90 degrees to conveyor axis of motion).

Each of the five portions was subdivided into an exploratory and a confirmatory phase which would statistically establish the desired non-propagation distance. When necessary, each portion was further subdivided into free air tests and tests with barriers or shields between the explosive units.

Test Specimens

The test specimens utilized during the program were either sub-components of, or completely assembled, 105mm M456 HEAT-T Cartridges, depending on what portion of the assembly line was being simulated. Included in the test specimens were M83 Primers, loaded M148 Cartridge Cases, loaded projectiles and complete cartridges.

The 105mm M456 HEAT-T Cartridge (fig. 2) is one of a family of high-explosive anti-tank cartridges intended for use against armored targets. It consists of a steel projectile body fitted with a plastic obturator, a threaded standoff spike assembly, a fin-and-boom assembly, and a PIBD (Point Initiating Base Detonating) fuze element.

A funnel-shaped copper liner within the projectile's body shapes the explosive charge consisting of 0.97 kg (2.14 lb) of Composition B. A piezoelectric fuze element, retained within a nose cap, is fitted to the forward end of the spike assembly and is electrically connected to the base detonating M509A1 fuze. The fin-and-boom assembly is hollowed out and contains an M13 Tracer element.

The M148 Cartridge case is a cylindrical container, open to receive the projectile at one end, and containing an M83 Primer at the other. The cartridge case is loaded with either 5.6 kg (12.5 lb) of small grained or 5.1 kg (11.5 lb) of large grained M30A1 propellant. The overall length of the completely assembled cartridge is 1.0 m (39 in) and the weight is 21.8 kg (48.0 lb).

Test Arrangements

During each test phase (with the exception of the primer test phase), a donor and two acceptor specimens were utilized. The specimens were raised off the ground to simulate the height of the assembly line. The center specimen was always initiated (donor), while the others served as acceptors. This test configuration produced two acceptor test data results for each detonation. The separation distances between the donor and acceptor specimens were varied during single test firing and also between tests. However, for the confirmatory phase, this distance was always held constant.

M83 Primer Test Array

Initially, the primer test phase was to involve a series of exploratory and confirmatory tests, each utilizing as a test specimen an M148 Cartridge case with just the M83 Primer inserted in it. The cartridge case and primer assembly was to be vertically suspended with at least a 30-cm (12-in) clearance from the cartridge case to the existing terrain. However, it was decided to conduct a preliminary test to determine if an initiated primer would ever rupture the cartridge case containing it. If the initiated primer did not rupture its containing case, then there would be no need to continue with the testing. A series of five primer initiation tests were therefore conducted.

M148 Cartridge Case Test Array

The second portion of the safe separation program was the determination of the non-propagation distance between fully loaded M148 Cartridge cases [containing one M83 Primer and 5.6 kg (12.5 lb) of M30 Propellant]. Originally, a series of exploratory tests followed by 25 confirmatory tests were planned for this portion of the program, each test utilizing the one donor/two acceptor test array. However, only a few tests were conducted.

The test array, figure 3, consisted of three test specimens oriented in a vertical, open end-up position. Each test specimen was placed on an aluminum transfer plate 58.0 cm (23.0 in) square by 1.6 cm (0.64 in) thick, supported by low density concrete blocks approximately 46.0 cm (18.0 in) above the existing terrain in order to simulate the LAP conveyor system. Upon the completion of three tests [with cartridge centerline spacing of 58.0 cm (23.0 in)], the testing was discontinued at the request of the loading line designers. It was decided that the spacing used for the completely loaded cartridges could be utilized for the cartridge case transfer pallet.

M456 Projectile Test Array

The third scheduled portion of the safe separation program was the projectile non-propagation tests. Again, a series of exploratory and confirmatory tests were planned, each to utilize the test configuration shown in figure 4. Each projectile was to be positioned vertically (nose up) on a transfer pallet and testing was to start at a projectile centerline spacing of 38.5 cm (15.0 in). However, testing of this projectile was never done, since the loading line designer

decided to also utilize the separation distance on the conveyor system for the completely assembled cartrige.

M456 Cartridge Vertical Test Array

The fourth scheduled portion of the program was non-propagation testing of completely assembled M456 Cartridges (projectiles, fuze and loaded cartridge case) positioned and aligned to simulate their actual LAP facility conditions during transfer from one loading operation to the next. A series of exploratory and confirmatory tests were planned, each to utilize the test array shown in figure 5. Each cartridge was positioned in a vertical, nose-up configuration on a transfer pallet, and located at a centerline spacing of 58.4 cm (23 in). After three exploratory tests, the test configuration was revised to include a shield positioned half-way between the donor and acceptor cartridges. An aluminum bar (6061-T6), 7.6 cm (3 in) in diameter and 115 cm (45.0 in) in height, welded to aluminum base plates, was used for shielding. A total of 25 confirmatory tests were conducted at a cartridge centerline distance of 58.4 cm (23.0 in) in order to amass the necessary statistical data.

M456 Cartridge Horizontal Test Array

The fifth and final portion of this safe separation program was the testing of completely assembled M456 Cartridges, positioned and aligned to simulate their actural LAP facility conditions during transfer from one loading operation to the next, along a walkway beam conveyor system. A series of exploratory and confirmatory tests were planned, each to utilize the test array shown in figure 6, in which each cartridge was positioned horizontally, with the donor and acceptor projectiles in a parallel array. In all testing, the centerline distance between cartridges was 38.1 cm (15.0 in) in order to conform to standard walking beam conveyor spacing. Also, all testing utilized an aluminum bar (6061-T6), 7.6 cm (3.0 in) in diameter and 115 cm (45.0 in) in length, as a shield located parallel to, and halfway between, the cartridges. Only two exploratory tests were conducted, followed by 25 confirmatory tests.

Method of Initiation

Due to the complexity of the test program, a number of ignition systems were utilized, dependent upon the nature of the test specimens. In the tests of the M83 Primers, the donors were initiated electrically to match their normal weapon-functioning method. However, in the tests of the M148 Cartridge cases, the M30 Propellant was primed with a 0.12-kg (4-oz) charge of

Composition C4 and initiated electrically by an engineer's special J2 blasting cap.

For the final two test phases, namely, the complete M456 Cartridge, both vertically and horizontally oriented, a special initiation system was utilized. The M509 BD Fuze was removed from its well in the base of the projectile and a 0.06-kg (2-oz) charge of Composition C4 with a J2 electrical blasting cap was inserted. Appropriate holes were drilled in the fuze lock plug, tail boon and cartridge case, to allow electrical access to the blasting cap. In both of these test phases, no attempt was made to separately initiate the M30 Propellant nor the M83 Primer to a high order detonation.

TEST RESULTS

General

As previously stated, the safe separation distance study program for the 105mm M456 HEAT-T Cartridge consisted of five separate test portions, each corresponding to points on the facility line layout. Each test portion was further subdivided into two test sections; namely, exploratory and confirmatory tests. The results of the various tests are discussed below.

M83 Primer

A total of five tests were conducted in which an M83 Primer, attached to an empty M148 Cartridge case, was electrically initiated. In all cases, the primer functioned properly and its explosive elements were fully consumed without any visible damage to the cartridge case. Since the cartridge case containing the primer was undamaged, testing for a safe separation distance between units was therefore unnecessary. Figure 7 is a pre-test view of the inside of a cartridge case showing the loaded primer and case liner, and figure 8 is a post-test view of the same firing. Note that the only damage done to the case was the ejection of the case liner, which was also undamaged.

M148 Cartridge Case

Only three tests were conducted utilizing the M148 Cartridge case containing an M83 Primer and 5.6 kg (12.5 lb) of M30 Propellant. In all three cases, a centerline spacing of 58.0 cm (23.0 in) was used, with no propagation being recorded. Upon review of the data, with a facility layout representative, it was decided to discontinue this test phase and utilize distances determined for complete cartridges for the whole main conveyor system.

Figure 9 is a pre-test view of the M148 Cartridge case test array showing the simulated transfer pallets. The acceptors were color-coded for ease of post-test analysis. Figure 10 is a post-test general view. Note that both acceptor cases were only knocked over by the donor detonation and not really displaced laterally by the blast. Figure 11 is a post-test close-up view of the right-hand acceptor case showing the spilled, but unburned, M30 Propellant.

M456 Projectile

There were no tests performed in this portion of the non-propagation program. After a discussion with the facility layout representative, it was decided to disregard this test phase and utilize the distances determined for complete cartridges for this supply conveyor system.

M456 Cartridge, Vertical

A total of three exploratory tests were conducted on unshielded cartridges in the vertical loading position (with centerline separation distances from 58.4 to 91.4 cm (23.0 to 36.0 in). While there was no recorded propagation of a donor detonation to an acceptor cartridge, there was sufficient damage to the unshielded acceptors to anticipate an eventual acceptor detonation. Figure 12 is a pre-test view of the unshielded test array with the donor cartridge primed and figure 13 is a post-test view of the same test firing. Figure 14 is a post-test close-up of an acceptor projectile. Note the number of fragment hits and the large penetration hole. Since greater separation distances could not be tolerated within the confines of the line layout, a series of tests utilizing a shield between the cartridges were performed.

A total of 26 exploratory and confirmatory tests were conducted on vertical cartridges, utilizing a 7.6-cm (3.0-in) diameter aluminum bar as a shield between cartridges. All tests were conducted at a cartridge centerline distance of 58.4 cm (23.0 in) with the shielding bar being located half-way between the cartridges. Table 1 is a detailed summary of the test data. Figure 15 is a pre-test view of the vertical shielded test array and figure 16 is a post-test view of a similar test. Note that while the donor projectile was fully consumed, the cartridge case and propellant were not. Also note the amount of damage to the shielding bars (fig. 17).

M456 Cartridge, Horizontal

Based upon the data from the unshielded, vertically oriented cartridge separation tests and the desired facility layout spacing of 38.1 cm (15.0 in) for the walking beam conveyor system planned for the horizontally oriented cartridges, no unshielded tests were conducted.

A total of 27 exploratory and confirmatory tests were conducted on horizontally oriented cartridges, each utilizing a 7.6-cm (3.0-in) diameter aluminum bar as a shield between the

cartridges. All tests were conducted at a cartridge centerline distance of 38.1 cm (15.0 in) with the shielding bar being located half-way between the cartridges. Table 2 is a detailed summary of the test data. Figure 18 is a pre-test view of the horizontally oriented shielded test array and figure 19 is a post-test view of the same test. Note, as in the vertically oriented shielded tests, that the cartridge was undamaged while the shielding bar absorbed all the fragment hits. Also note that, while the donor's projectile functioned to a high order detonation, its cartridge case was not fully consumed.

Summary of Test Results

During the original analysis of the M456 Cartridge line layout, five areas were considered in need of non-propagation distance analysis (primers, cartridge cases, projectiles, vertical and horizontal cartridges). Of these items, two (cartridge cases and projectiles) had their test requirements negated and replaced by distances derived from cartridge assemblies containing greater amounts of explosives, thus presenting a much "worst case" or safer condition. A third item (primers) was so well encased within its cartridge case assembly, that only a small number of tests were necessary to determine that the primer alone would never rupture its own case, much less propagate to the next one. For the complete M456 Cartridge, in both the vertical and horizontal positions, sufficient tests were conducted, utilizing an aluminum shield to establish centerline distances of 58.4 and 38.1 cm (23.0 and 15.0 in), respectively. However, it should be noted that the established distances are not minimum distances, but only non-propagation distances to satisfy a given facility line layout.

Analysis of Test Results

Variations in manufacturing tolerances, materials, wear, etc., required that statistical reasoning be employed in the interpretation of the confirmatory test data. The actual probability of a continuous propagation of an unexpected explosive incident on a LAP facility ammunition production line is a function of the number of propagation occurrences in a particular test phase as related to the total number of test detonations conducted (see appendix A for statistical theory).

In the vertical oriented cartridge tests, utilizing an aluminum shielding bar, there was a total of 52 observations recorded at the 58.4-cm (23.0-in) safe separation distance, resulting in an upper limit of 6.85 percent probability of propagation of an explosive incident at the 95 percent confidence

level. The horizontally oriented cartridge tests, also utilizing an aluminum shielding bar, had a total of 54 observations recorded at the 38.1-cm (15.0-in) safe separation distance; this resulted in an upper limit of 6.60 percent probability of propagation of an explosive incident at the 95 percent confidence level.

These values are equivalent to stating that, in a large number of tests, 95 out of 100 times, the probability of an unexpected explosive incident propagating to a catatrosphic event will be less than, or equal to, the stated values above. These values indicate the quality of the test results and the reliance that can be placed upon the conclusions drawn from the data.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Sufficient M83 Primer tests were conducted without a single rupture to the M148 Cartridge case to safely state that a primer functioning will not propagate to adjacent primers within the automatic primer insertion machine configuration.

2. Use of the complete cartridge vertical distance for a loaded cartridge case and loaded projectile non-propagation distances, in lieu of individual tests, is a valid substitution, since the distance being utilized is for a "worst case" condition.

3. It may be concluded from the test results of the complete M456 Cartridge that, in both the vertical and horizontal orientation, a shield consisting of a 7.6-cm (3.0-in) diameter aluminum bar (6061-T6), with a height equal to the full height or length of the cartridges and positioned half-way between them, is necessary to prevent detonation propagation.

4. The safe separation distance for vertically oriented and shielded M456 Cartridges is 58.4 cm (23.0 in), with the probability of the propagation of an explosive incident being 6.85 percent at the 95 percent confidence level.

5. The safe separation distance for horizontally oriented and shielded M456 Cartridges is 38.1 cm (15.0 in), with the probability of the propagation of an explosive incident being 6.60 percent at the 95 percent confidence level.

6. It should be recognized that the safe separation distances determined within the constraints of this study program for 105mm M456 HEAT-T Cartridges are not necessarily the minimum non-propagation distances for the cartridges and sub-components tested.

Table 1. 105mm M456 HEAT-T Cartridge

(Shielded - Vertical position)

Test No.	Acceptor distance cm	Acceptor distance (in)	Barrier distance cm	Barrier distance (in)	Remarks
1L	58.4	(23.0)	25.4	(10.0)	NDP*, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
2L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
3L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
4L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
5L	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
6L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
7L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
8L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
9L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
10L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
11L	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage

* NPD - No Detonation Propagation

Table 1. 105mm M456 HEAT-T Cartridge

(Shielded - Vertical position) (cont'd)

Test No.	Acceptor distance cm	(in)	Barrier distance cm	(in)	Remarks
12L	58.4	(23.0)	25.4	(10.0)	NDP*, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
13L	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
14L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
15L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
16L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
17L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
18L	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
19L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
20L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
21L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage

* NPD - No Detonation Propagation

Table 1. 105mm M456 HEAT-T Cartridge

(Shielded - Vertical position) (cont'd)

Test No.	Acceptor distance cm	Acceptor distance (in)	Barrier distance cm	Barrier distance (in)	Remarks
22L	58.4	(23.0)	25.4	(10.0)	NDP*, projectile separated from case
R	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
23L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
24L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage
25L	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
R	58.4	(23.0)	25.4	(10.0)	NDP, projectile separated from case
26L	58.4	(23.0)	25.4	(10.0)	NDP, no damage
R	58.4	(23.0)	25.4	(10.0)	NDP, no damage

* NPD - No Detonation Propagation

Table 2. 105mm M456 HEAT-T Cartridge

(Shielded - Horizontal position)

Test No.	Acceptor distance cm	(in)	Barrier distance cm	(in)	Remarks
1L	38.1	(15.0)	19.0	(7.5)	NDP*, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
2L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
3L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
4L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
5L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
6L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
7L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
8L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
9L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
10L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage

* NPD - No Detonation Propagation

Table 2. 105mm M456 HEAT-T Cartridge

(Shielded - Horizontal position) (cont'd)

Test No.	Acceptor distance cm	(in)	Barrier distance cm	(in)	Remarks
11L	38.1	(15.0)	19.0	(7.5)	NDP*, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
12L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
13L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
14L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
15L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
16L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
17L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
18L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
19L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case

* NPD - No Detonation Propagation

Table 2. 105mm M456 HEAT-T Cartridge

(Shielded - Horizontal position) (cont'd)

Test No.	Acceptor distance cm	(in)	Barrier distance cm	(in)	Remarks
20L	38.1	(15.0)	19.0	(7.5)	NDP*, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
21L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
22L	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
23L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case
24L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
25L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
26L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, no damage
27L	38.1	(15.0)	19.0	(7.5)	NDP, no damage
R	38.1	(15.0)	19.0	(7.5)	NDP, projectile separated from case

* NPD - No Detonation Propagation

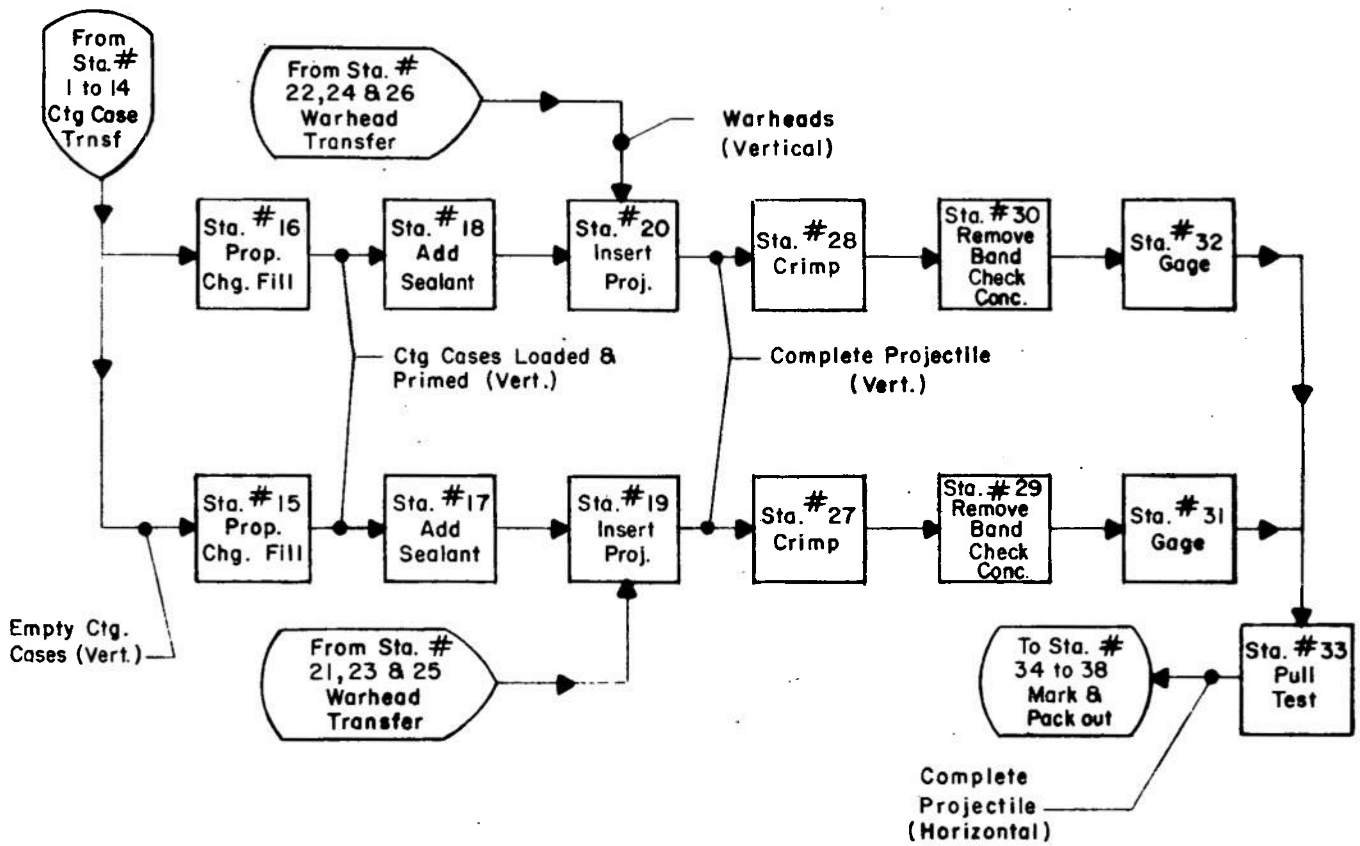

Figure 1. Assembly line schematic

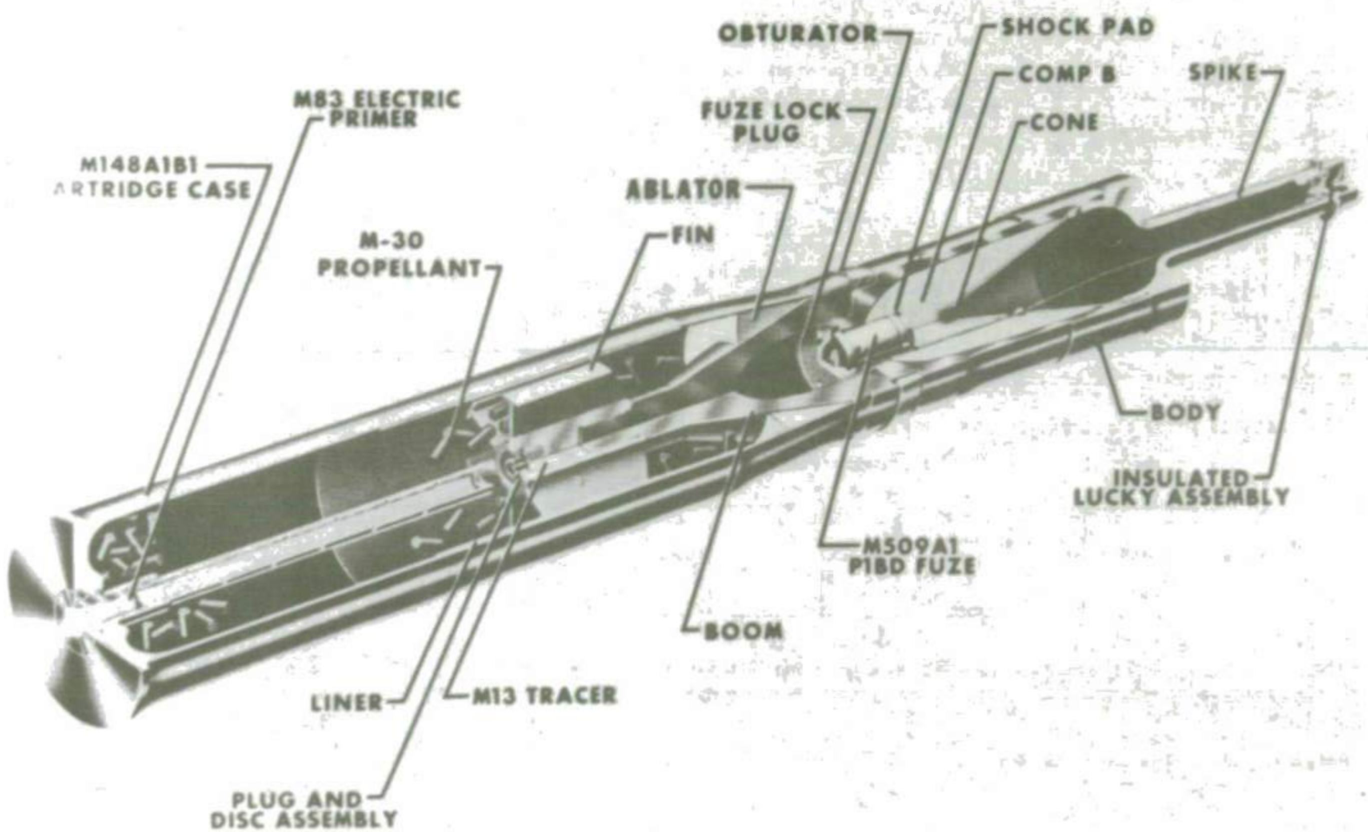

Figure 2. 105mm M456 HEAT-T Cartridge, cross-section view

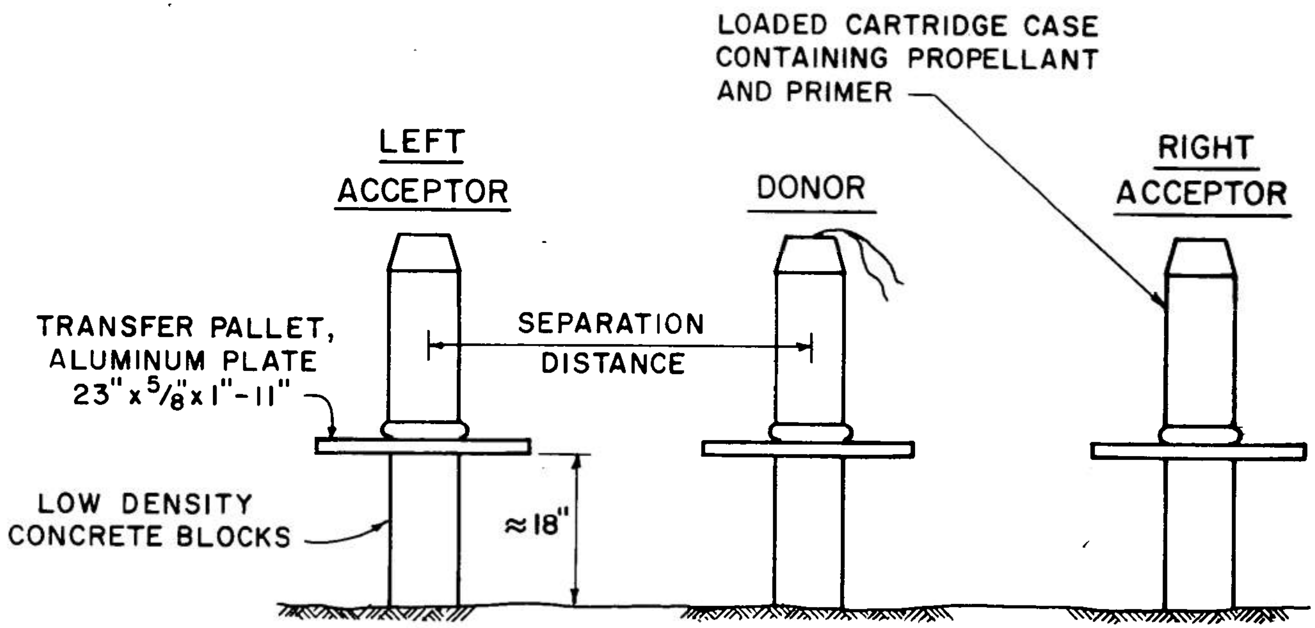

Figure 3. Cartridge case test array

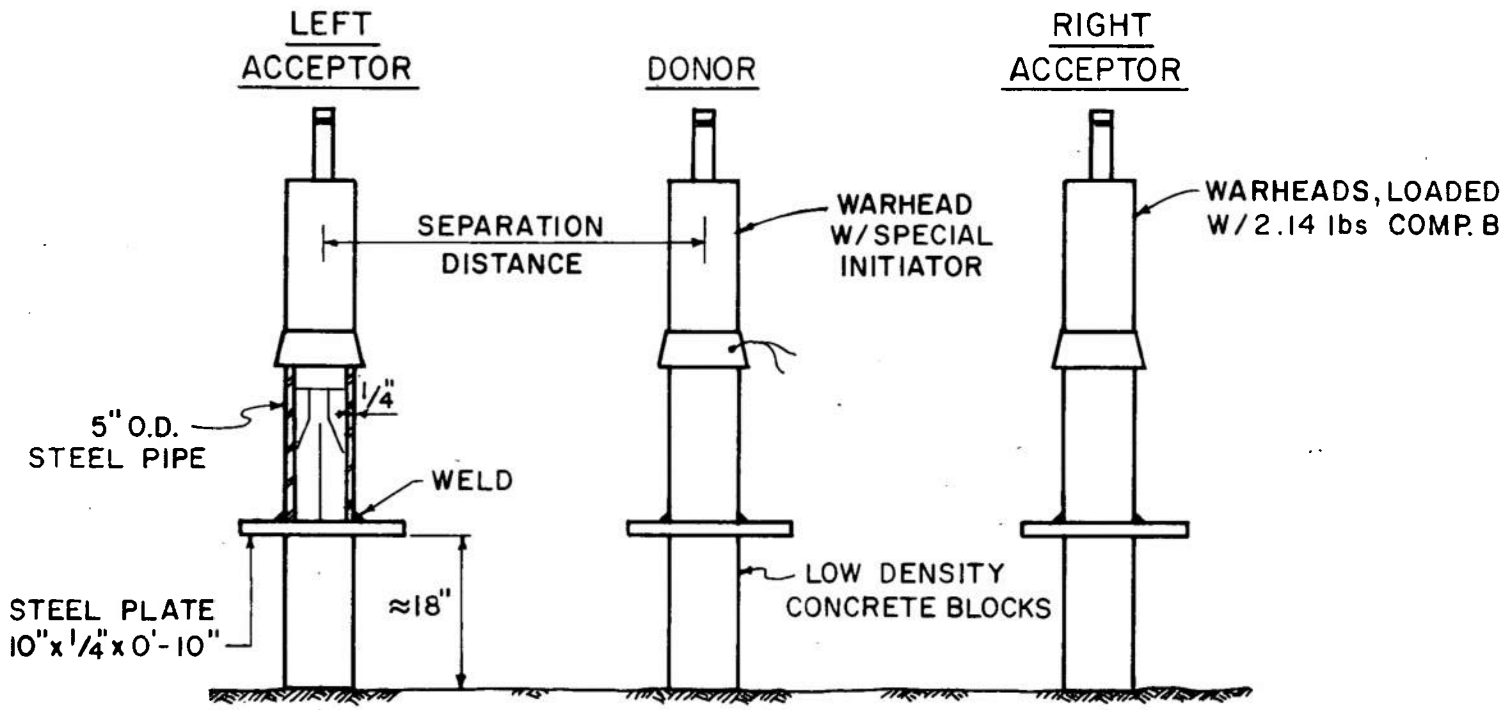

Figure 4. Projectile test array

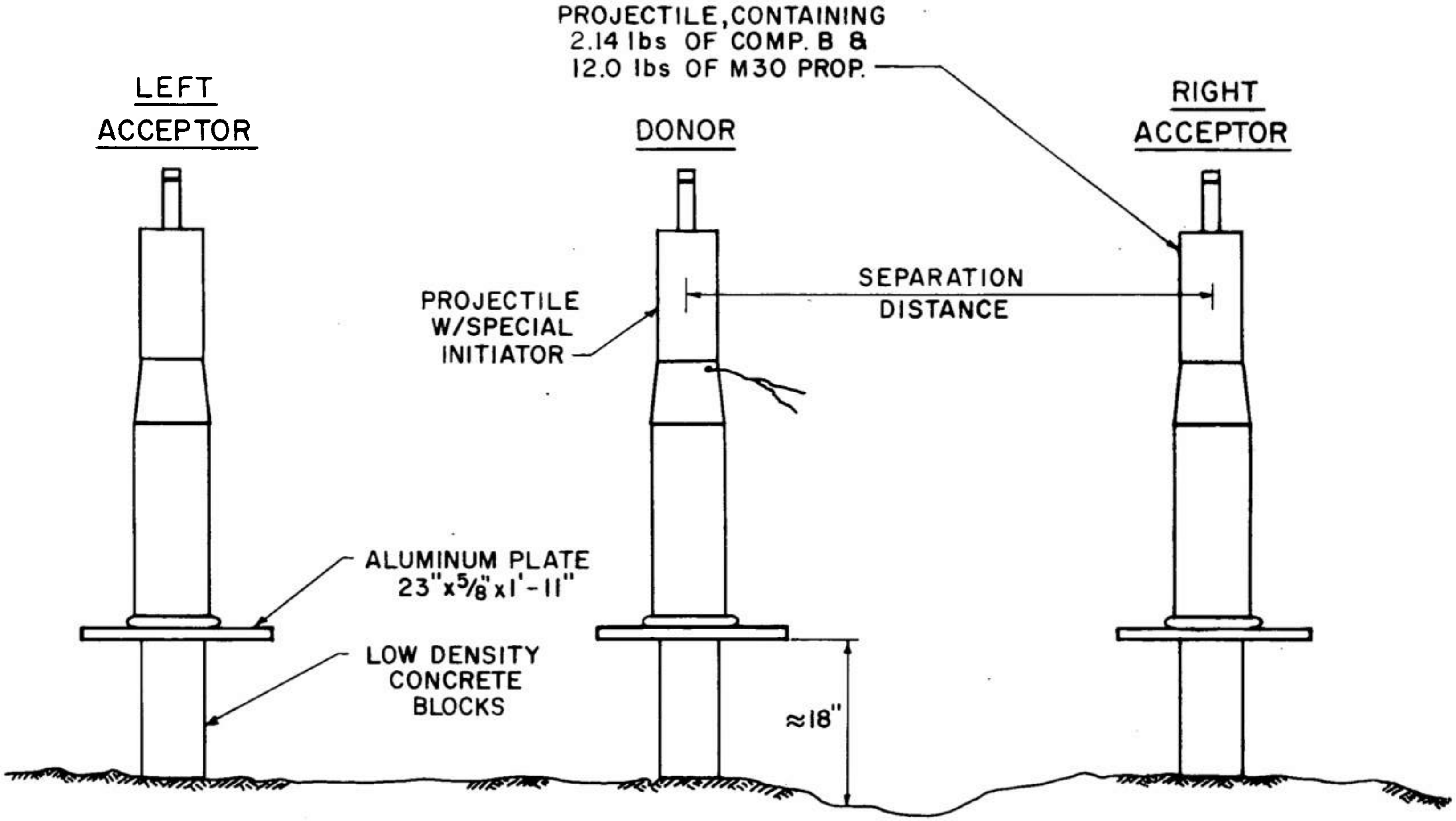

Figure 5. Cartridge, vertical test array

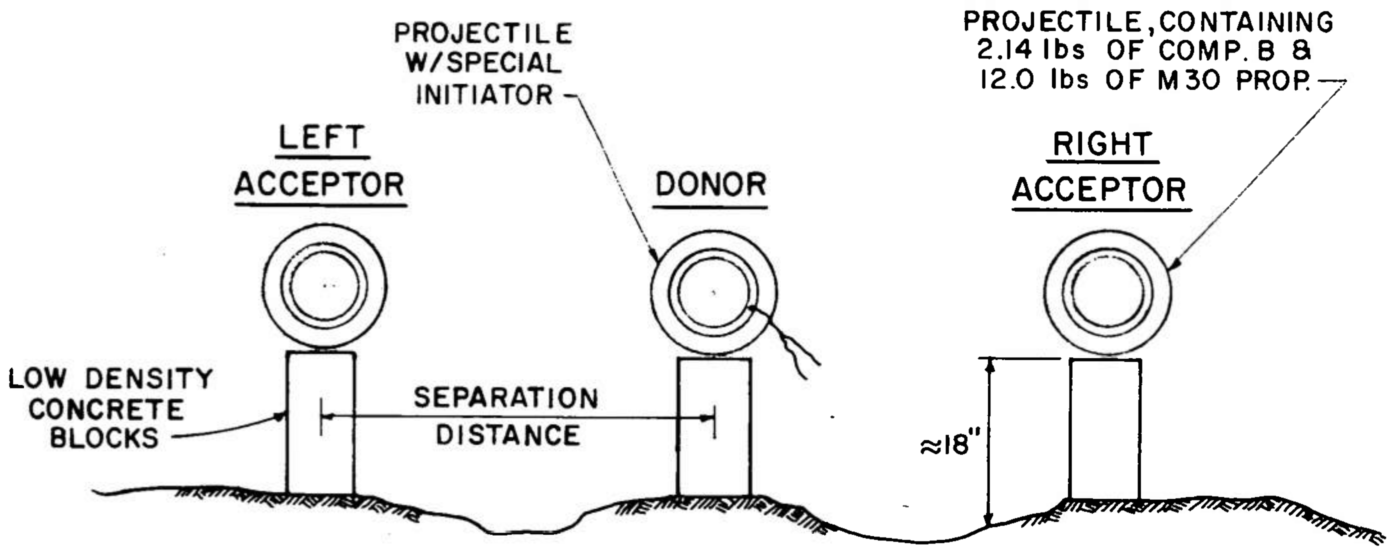

Figure 6. Cartridge, horizontal test array

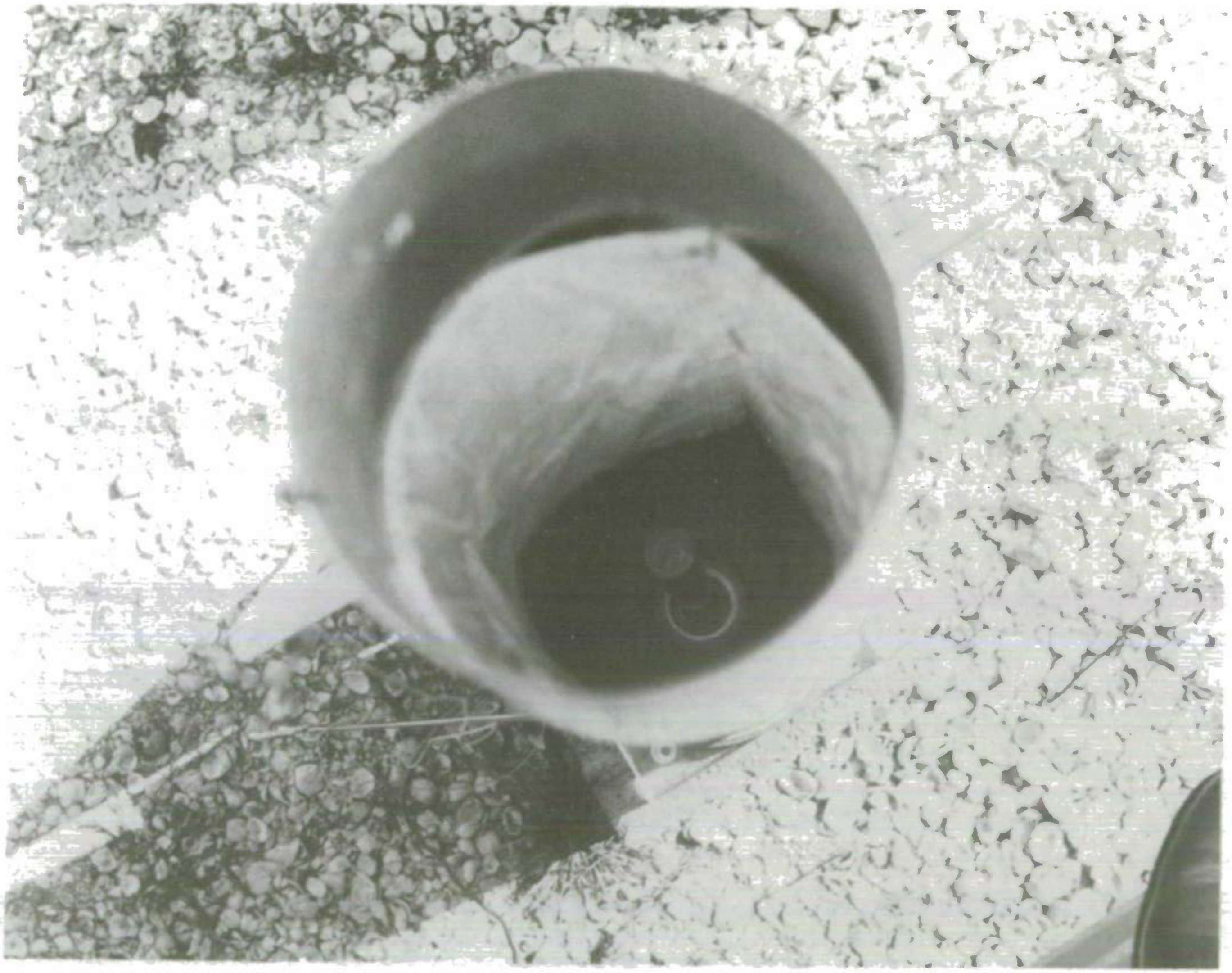

Figure 7. M83 Primer, pre-test view

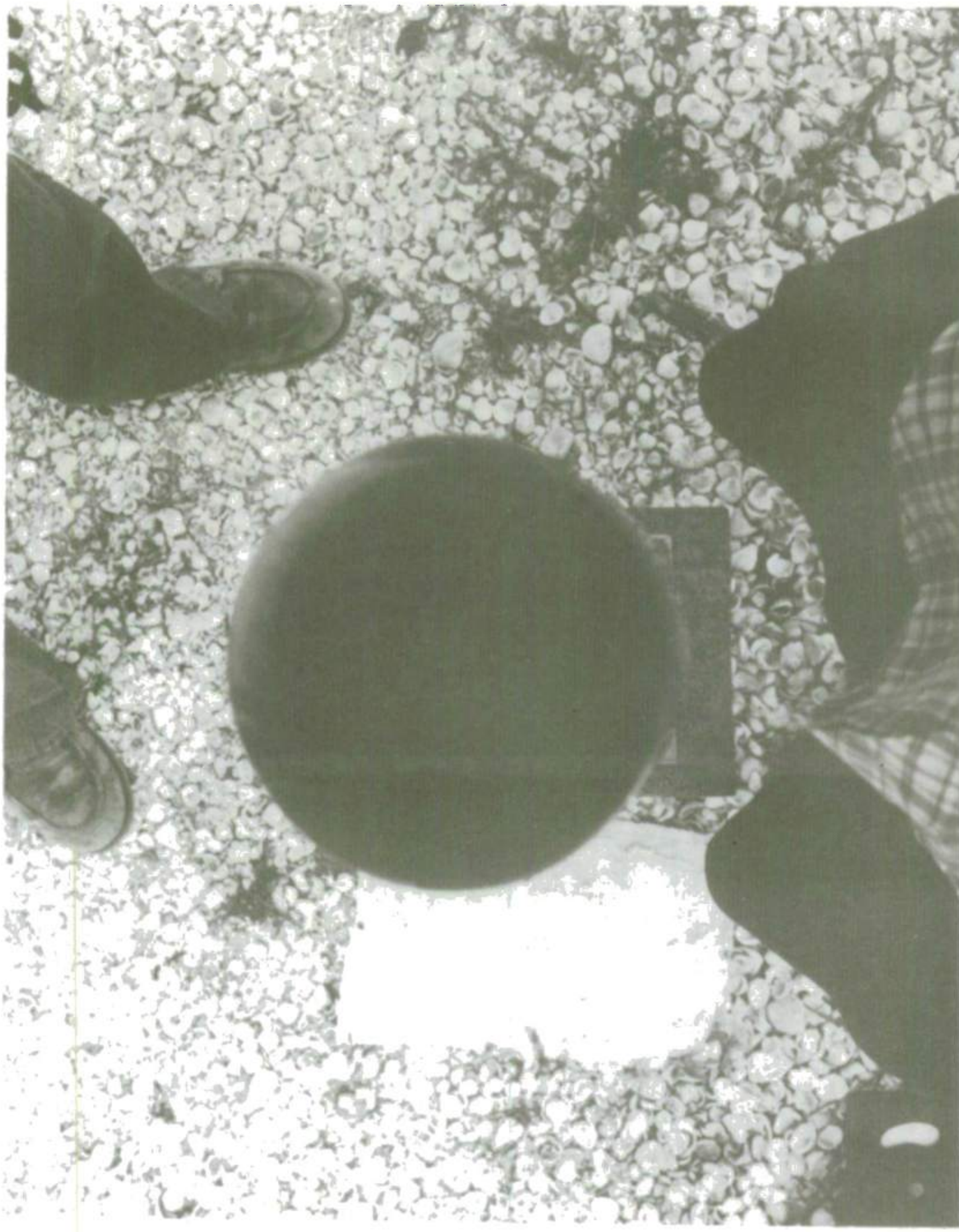

Figure 8. M83 Primer, post-test view

Figure 9. M184 Cartridge case, pre-test view

Figure 10. M184 Cartridge case, post-test view

Figure 11. M184 Cartridge case, post-test close-up

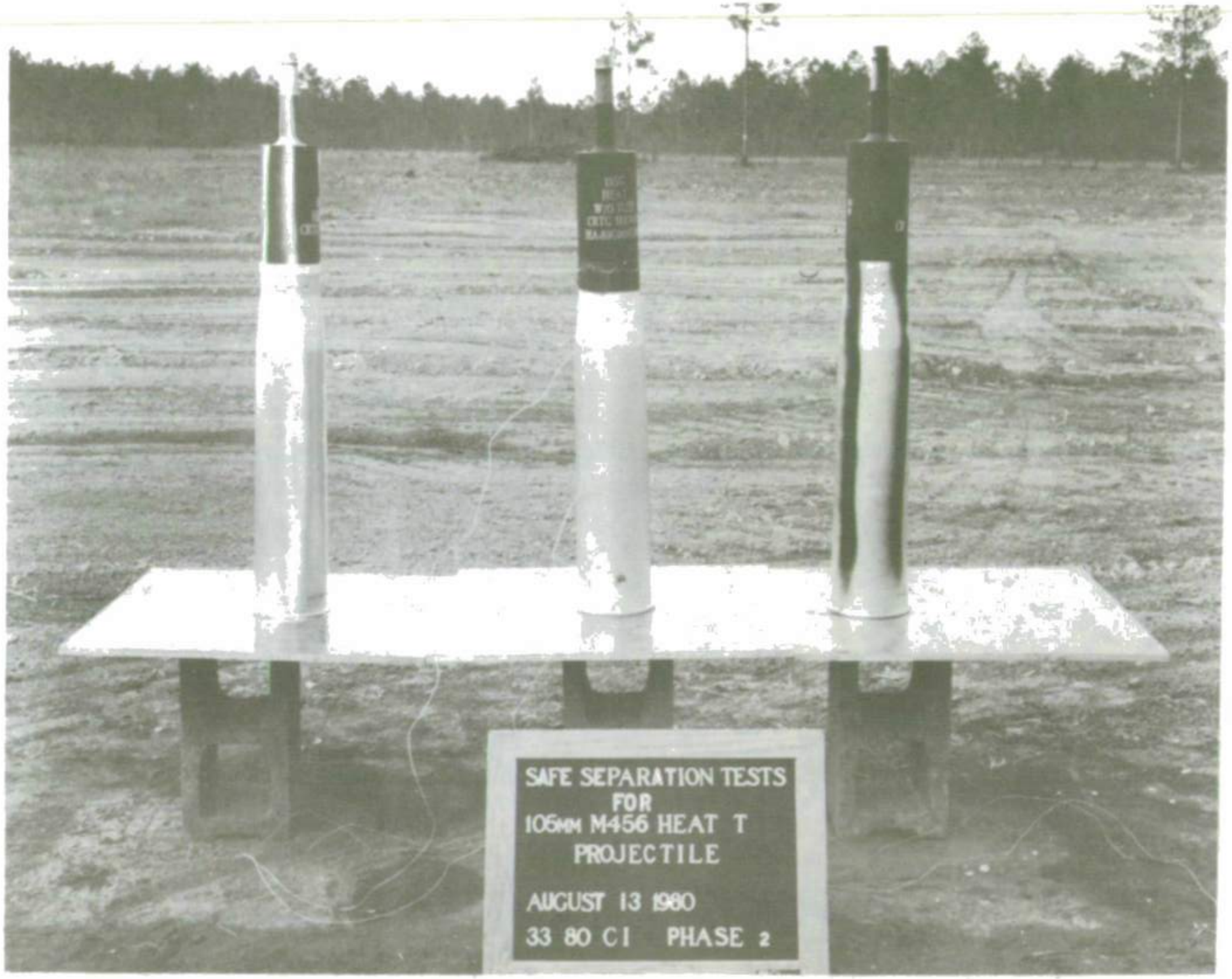

Figure 12. M456 Cartridge, vertical - unshielded, pre-test view

Figure 13. M456 Cartridge, vertical - unshielded, post-rest view

Figure 14. M456 Cartridge, vertical - unshielded, close-up

Figure 15. M456 Cartridge, vertical - shielded, pre-test view

Figure 16. M456 Cartridge, vertical - shielded, post-test view

Figure 17. M456 Cartridge, vertical - shielded, shield damage

Figure 18. M456 Cartridge, Horizontal - shielded, pre-test view

Figure 19. M456 Cartridge, horizontal - shielded, post-test view

APPENDIX. STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

Statistical Theory

The possibility of the occurrence of explosion propagation based upon a statistical analysis of the test results has been evaluated in the main body of the report. This appendix is devoted to the mathematical means by which the statistical analysis was performed.

The probability of the occurrence of an explosion propagation is dependent upon the degree of certainty or confidence level involved and has upper and lower limits. The lower limit for all confidence levels is zero; whereas the upper limit is a function of the number of observations or, in this particular case, the number of acceptor items tested. Since each observation is independent of the others and each observation has a constant probability of a reaction occurrence (explosion propagation), the number of reactions (x) in a given number of observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by

$$p = x/n \tag{1}$$

and, therefore, the expected value of (x) is given by

$$E(x) = np \tag{2}$$

Each confidence level will have a specific upper limit (p_2) depending upon the number of observations involved. The upper probability limit for a given confidence level α, when a reaction is not observed, is expressed as

$$(1 - p_2)^n = \varepsilon \tag{3}$$

where $$\varepsilon = (1 - \alpha)/2 \text{ and } \alpha < 1.0 \tag{4}$$

Use of equation 3 is illustrated in the following example:

<u>Example</u>

Determine the upper probability limit of the occurrence of an explosion propagation for a confidence level of 95% based upon 30 observations without a reaction occurrence.

Given

Number of Observations (n) = 30
Confidence Level (α) = 95%

Solution

1. Substitute the given value of (α) into equation 4 and solve for ε:

   $$\varepsilon = (1 - \alpha)/2 = (1 - 0.95)/2 = 0.025 .$$

2. Substitute the given value of (n) and value of (ε) into equation 3 and solve for p_2:

   $$\varepsilon = 0.025 = (1 - p_2)^{30}$$

   or

   $$p_2 = 0.116(11.6\%)$$

Conclusions

For a 95% confidence level and 30 observations, the true value of the probability of explosion propagation will fall between zero and 0.116; or statistically, it can be interpreted that in 30 observations, a maximum of (0.116 x 30) = 3.48 observations could result in a reaction for a 95% confidence level.

Probability Table

Table A-1 shows the probability limits and the range of the expected value E(x) for different numbers of observations. Three confidence limits, 90, 95 and 99%, are used to derive the probabilities. The same values are plotted in Figure A-1.

Table A-1. Probabilities of propagation for various confidence limits

Number of observations	90%	C.L.	95%	C.L.	99%	C.L.
n	p_2	E(x)	p_2	E(x)	p_2	E(x)
10	0.259	2.59	0.308	3.08	0.411	4.11
20	0.131	2.62	0.168	3.36	0.233	4.66
30	0.095	2.85	0.116	3.48	0.162	4.86
40	0.072	2.88	0.088	3.52	0.124	4.96
50	0.058	2.9	0.071	3.55	0.101	5.05
60	0.049	2.92	0.060	3.6	0.085	5.10
80	0.037	2.96	0.045	3.6	0.064	5.12
100	0.030	3.0	0.036	3.6	0.052	5.2
200	0.015	3.0	0.018	3.6	0.026	5.2
300	0.010	3.0	0.012	3.6	0.018	5.4
500	0.006	3.0	0.007	3.5	0.011	5.5

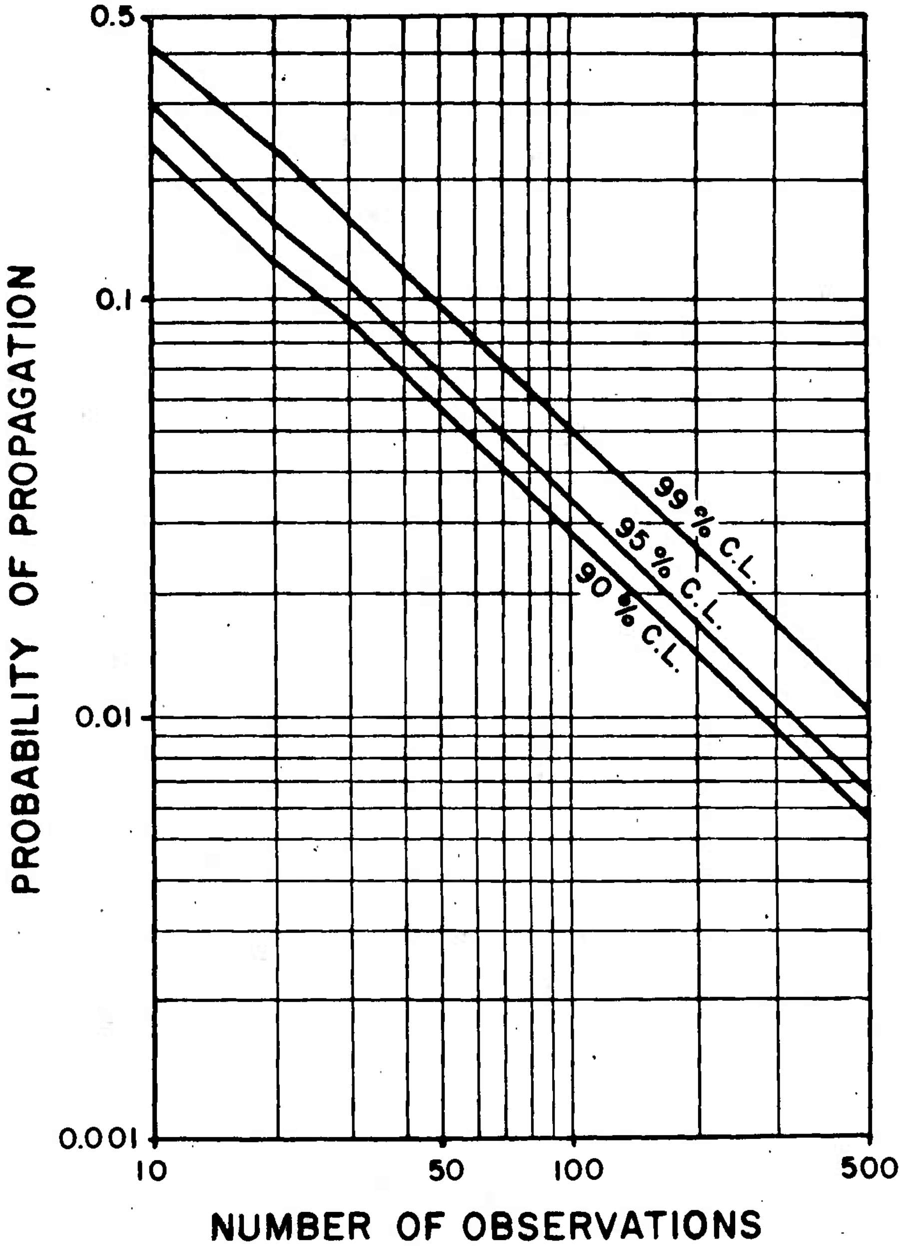

Figure A-1. Variation of propagation probability vs. number of observations as a function of confidence level

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